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(54) Title: MODIFIED GROWTH HORMONE

(57) Abstract: Growth hormone (GH) in which the regulated secretory pathway (RSP) sorting signal has been mutated as well as GH in which the three-dimensional conformation of the RSP sorting signal has been alterd, a composition comprising an effective amount of such a GH in an excipient, a nucleic acid molecule encoding GH in which the RSP sorting signal has been mutated such the GH can be constitutively secreted by the nonregulated secretory pathway (NRSP) in a mammalian cell as well as a nucleic acid molecule encoding GH in which the three-dimensional conformation of the RSP sorting signal has been altered such that the GH can be constitutively secreted by the NRSP in a mammalian cell, a vector comprising such a nucleic acid molecule, an isolated host cell comprising such a vector, a method of treating growth hormone deficiency (GHD) and other diseases in a mammal by administering to the mammal the aforementioned composition, nucleic acid or vector or host cells which have been contacted ex vivo with an aforementioned nucleic acid or vector a method of making a GH in which the RSP sorting signal is mutated comprising mutating one or more amino acids in the RSP sorting signal in GH and the GH so produced, a method of making a GH in which the three-dimensional conformation of the RSP sorting signal is altered comprising mutating one or more amino acids outside of the RSP sorting signal in GH is altered and the GH so produced, a method of making a nucleic acid molecule encoding a GH that can be constitutively secreted by the NRSP in a mammalian cell comprising mutating one or more codons encoding amino acids in the RSP sorting signal in a nucleic acid molecule encoding GH and the nucleic acid molecule so produced, and a method of making a nucleic acid molecule encoding a GH that can be constitutively secreted by the NRSP in a mammalian cell comprising mutating one or more condons encoding amino acids outside of the RSP sorting signal in a nucleic acid molecule encoding GH and the nucleic acid molecule so produced.

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MODIFIED GROWTH HORMONE

TECHNICAL FIELD OF THE INVENTION

The present invention relates to modified growth hormone and related compositions,
5   nucleic acids, vectors, isolated host cells comprising such vectors, and methods of
manufacture and use.

BACKGROUND OF THE INVENTION

Growth hormone acts through binding to membrane receptors that belong to the
10   cytokine receptor superfamily (Finidori, Vitam. Horm. 59: 71-97 (2000)). Ligand binding
induces receptor dimerization and activation of the receptor-associated kinase JAK-2,
resulting in phosphorylation of the kinase, the receptor and many cellular proteins (Finidori
(2000), *supra*). Activation by growth hormone is very transient and several mechanisms are
involved in downregulation, including internalization and degradation of the receptor and
15   recruitment of phosphatases or specific inhibitors of the JAK/Stat pathway, namely the
SOCS proteins (Finidori (2000), *supra*).

There are variant forms of human growth hormone (hGH) which include a disulfide
dimer, a glycosylated form (20 kD hGH) and two pituitary peptides made up of portions of
22 kD hGH (Lewis et al., Endocr. J. 47 Suppl: S1-8 (March 2000)). The two pituitary
20   peptides (hGH (1-43) and hGH (44-191)) have, respectively, insulin-potentiating and anti-
insulin properties (Lewis et al. (March 2000), *supra*). The smaller peptide may be useful in
decreasing the amount of exogenous insulin required by diabetics, whereas the larger
peptide may be involved in diabetic retinopathy (Lewis et al. (March 2000), *supra*).

The increased availability of growth hormone (GH) in the mid-1980s, due to
25   advances in recombinant DNA technology, has allowed research into the use of this
hormone at physiological dosage as replacement therapy for adults and children with GH
deficiency (GHD) (see, e.g., Carroll et al., Trends Endocrinol. Metab. 11(6): 231-238
(August 2000)) and at pharmocological dosages as a possible therapeutic agent for a number
of disease states (Murray et al., Expert Opin. Pharmacother. 1(5): 975-990 (July 2000); see,
30   also, Wit, Endocr. Regul. 34(1): 28-32 (March 2000)). Such disease states include frailty
associated with ageing, osteoporosis, morbid obesity, cardiac failure, major thermal injury,
hypoglycemic unawareness in diabetes mellitus (Sonksen et al., U.S. Pat. No. 5,426,096,
issued June 20, 1995), various acute and chronic catabolic conditions (Murray et al. (July
2000), *supra*; see, also, Mehls et al., Growth Horm. IGF Res. 10 Suppl. B: S31-37 (April
35   2000)) and intoxication with poisonous substances that are degraded in the liver by

microsomal enzymes (Jorgensen, U.S. Pat. No. 4,816,439, issued March 28, 1989). In combination with DHEA, its use has been proposed for regenerating an involuted thymus (Fahy, International Patent Application WO 95/32991, published December 7, 1995).

GHD in humans is currently treated by growth hormone injection. The problem with such a treatment method is that injections are required every day or couple of days (MacGillivray et al., J. Clin. Endocrinol. Metab. 81(5):1806-1809 (May 1996)). The present invention seeks to overcome such a problem. This and other objects and advantages, as well as additional inventive features, will become apparent from the detailed description provided herein.

BRIEF DESCRIPTION OF THE INVENTION

The present invention provides an isolated and purified GH in which the regulated secretory pathway (RSP) sorting signal has been mutated as well as an isolated and purified GH in which the three-dimensional conformation of the RSP sorting signal has been altered. Also provided is a composition comprising an effective amount of such an isolated and purified GH in an excipient.

Further provided is an isolated and purified nucleic acid molecule encoding GH in which the RSP sorting signal has been mutated such that the GH can be constitutively secreted by the nonregulated secretory pathway (NRSP) in a mammalian cell as well as an isolated and purified nucleic acid molecule encoding GH in which the three-dimensional conformation of the RSP sorting signal has been altered such that the GH can be constitutively secreted by the NRSP in a mammalian cell. Still further provided are a vector comprising such an isolated and purified nucleic acid molecule and an isolated host cell comprising such a vector.

A method of treating GHD in a mammal is also provided. The method comprises administering to the mammal the aforementioned composition, nucleic acid or vector, wherein the nucleic acid or vector expresses an effective amount of the encoded GH and whereupon GHD in the mammal is treated.

Also provided are a method of making a GH in which the RSP sorting signal is mutated and the GH so produced. The method comprises mutating one or more amino acids in the RSP sorting signal in GH, whereupon a GH in which the RSP sorting signal is mutated is obtained.

Still also provided are a method of making a GH in which the three-dimensional conformation of the RSP sorting signal is altered and the GH so produced. The method comprises mutating one or more amino acids outside of the RSP sorting signal so that the three-dimensional conformation of the amino acids of the RSP sorting signal in GH is

altered, whereupon a GH with an RSP having an altered three-dimensional conformation is
obtained.

      Similarly provided is a method of making a nucleic acid molecule encoding a GH
that can be constitutively secreted by the NRSP in a mammalian cell and the nucleic acid

5   molecule so produced. The method comprises mutating one or more codons encoding
amino acids in the RSP sorting signal in an isolated and purified nucleic acid molecule
encoding GH such that, upon expression in a mammalian cell, the GH can be constitutively
secreted by the NRSP in a mammalian cell.

      Also similarly provided is a method of making a nucleic acid molecule encoding a

10   GH that can be constitutively secreted by the NRSP in a mammalian cell and the nucleic
acid molecule so produced. The method comprises mutating one or more codons encoding
amino acids outside of the RSP sorting signal in an isolated and purified nucleic acid
molecule encoding GH such that the three-dimensional conformation of the amino acids of
the RSP sorting signal in GH is altered and, upon expression in a mammalian cell, the GH

15   can be constitutively secreted by the NRSP in a mammalian cell.

BRIEF DESCRIPTION OF THE FIGURE

      Fig. 1 sets forth nucleic acid (SEQ ID NO: 1) and amino acid (SEQ ID NOS: 2
(lower case letters represent single letter designations of amino acids in accordance with

20   convention) and 3) sequences with respect to GH and modified GH.

DETAILED DESCRIPTION OF THE INVENTION

      The present invention provides an isolated and purified GH in which the RSP
sorting signal has been mutated. Any GH can be modified in accordance with the present

25   invention. Preferably, the GH is mammalian. Particularly preferred is hGH. The amino
acid sequence of hGH is known (Genbank accession no. A 15072; see also biosynthetic
hGH of Dalboge et al., U.S. Patent No. 5,633,352, issued May 27, 1997, and U.S. Patent
No. 5,635,604, issued June 3, 1997) and is reproduced herein as SEQ ID NO: 2 (see Fig. 1).
By "mutated" is meant chemical modification, substitution, deletion or insertion. Methods

30   of chemical modification, substitution, deletion and insertion are known in the art and
include *in vitro* chemical synthesis (e.g., Merrifield synthesis) of the desired mutant GH
(see, e.g., Barany et al., in *The Peptides*, Gross and Meienhofer, eds. Academic Press: New
York (1979), Vol. 2, pp. 3-254; and Parkhurst et al., J. Immunol. 157: 2539-2548 (1996)).
Substitution is preferred. Preferably, the isolated and purified GH consists essentially of the

35   amino acid sequence of SEQ ID NO: 2 in which the sorting signal comprises glutamic acid
at amino acid position 174 (Glu 174), leucine at amino acid position 177 (Leu 177), valine

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at amino acid position 185 (Val 185) and glutamic acid at amino acid position 186 (Glu 186) and one or more of the aforementioned amino acids is mutated. Preferably, each of Glu 174 and Glu 186 is mutated, preferably by substitution with alanine.

Especially preferred is when the isolated and purified GH consists essentially of the
5   amino acid sequence of SEQ ID NO: 2 in which the sorting signal comprises glutamic acid at amino acid position 174 (Glu 174), leucine at amino acid position 177 (Leu 177), valine at amino acid position 185 (Val 185) and glutamic acid at amino acid position 186 (Glu 186), each of Glu 174 and Glu 186 is substituted with alanine, and Phe 191 is substituted with LLGILQISSTVAAARV (see SEQ ID NO: 3 in Fig. 1). Optionally, Leu 177 and/or
10   Val 185 is/are mutated, such as by substitution.

Also provided is an isolated and purified GH in which the three-dimensional conformation of the RSP sorting signal has been altered. Preferably, the isolated and purified GH consists essentially of the amino acid sequence of SEQ ID NO: 2 in which the sorting signal comprises Glu 174, Leu 177, Val 185 and Glu 186 and in which one or more
15   amino acids outside of the RSP sorting signal is mutated. Preferably, the cysteine at amino acid position 189 (Cys 189) is mutated, preferably by substitution with serine.

While the above-described mutations are preferred, other mutations that either interfere with the charge of the acidic residues or alter the three-dimensional conformation of the sorting signal are possible. For example, a positively charged residue(s), such as
20   arginine or lysine, can be introduced close to or beside either one or both of the glutamic acid residues in order to neutralize the acidic charge of the neighboring glutamic acid residue. Alternatively, a proline residue can be introduced near the sorting signal so as to alter the three-dimensional conformation of the sorting signal region.

In view of the above, the present invention also provides a composition comprising
25   an effective amount of an above-described isolated and purified GH in an excipient, such as a vehicle, adjuvant, carrier or diluent, which is desirably pharmaceutically acceptable, as known in the art. See, for example, *Pharmaceutics and Pharmacy Practice*, J. B. Lippincott Co., Philadelphia, PA, Banker and Chalmers, eds. (1982), and ASHP Handbook on Injectable Drugs, Toissel, 4th ed. (1986).

30   Such compositions can further comprise asparagine (Sorensen, U.S. Patent No. 5,851,992, issued December 22, 1998). Injectable aqueous formulations, such as those which comprise a buffer, nonionic surfactants and neutral salts are known in the art (see, e.g., O'Connor et al., U.S. Patent No. 5,763,394, issued June 9, 1998; and U.S. Patent No. 5,981,485, issued November 9, 1999). Sustained-release compositions, such as those
35   comprising GH complexed with a metal, such as zinc, are described by Johnson et al. (U.S. Patent No. 5,667,808, issued September 16, 1997). Metal-complexed GH can be further

combined with a biocompatible polymer (see, e.g., Johnson et al., U.S. Patent No. 5,654,010, issued August 5, 1997; U.S. Patent No. 5,891,478, issued April 6, 1999; U.S. Patent No. 6,051,259, issued April 18, 2000; and International Patent Application WO 96/40072). Glycine and mannitol also can be used to stabilize GH for parenterally

5   administered formulations (see, e.g., Pikal et al., U.S. Patent No. 5,612,315, issued March 18, 1997; and Pearlman et al., U.S. Patent No. 5,096,885, issued March 17, 1992). Saccharose, alone or in further combination with mannitol, can be used to stabilize GH as a solid intimate mixture (see, e.g., Samaritani, U.S. Patent No. 5,898,030, issued April 27, 1999). Injectable GH formulations which comprise citrate can be stable for at least 12

10   months (see, e.g., Castensson et al., U.S. Patent No. 5,567,677, issued October 22, 1996). Solubility of GH in an aqueous solution can be enhanced by the presence of creatinine, an acetyl tryptophan salt and/or nicotinamide (see, e.g., U.S. Patent No. 6,013,773, issued January 11, 2000).

        Also in view of the above, the present invention provides an isolated and purified

15   nucleic acid molecule encoding GH in which the RSP sorting signal has been mutated such that the hGH can be constitutively secreted by the nonregulated secretory pathway (NRSP) in a mammalian cell. Any nucleic acid molecule encoding a GH can be modified in accordance with the present invention. Preferably, the GH is mammalian. Particularly preferred is hGH. The nucleotide sequence of hGH is known (Genbank accession no. A

20   15072) and is reproduced herein as SEQ ID NO: 1 (see Fig. 1). Methods of introducing mutations at the nucleic acid level are known in the art and include the methods of Example 1, site-specific mutagenesis (Carter et al., Nucl. Acids Res. 13: 4331 (1986); and Zoller et al., Nucl. Acids Res. 10: 6487 (1987)), cassette mutagenesis (Wells et al., Gene 34: 315 (1985)), restriction selection mutagenesis (Wells et al., Philos. Trans. R. Soc. London SerA

25   317: 415 (1986)) and DNA synthesis of the mutated GH. When modifying the nucleic acid so that a new amino acid is substituted for that which is naturally occurring, the codon encoding the amino acid sequence to be substituted may be any of the alternative codons known to code for the particular amino acid (see, e.g. Lewin, GENES V, Oxford University Press, page 172 (1994)). For example, when the desired substitution is to result in the

30   amino acid alanine, the codons which could be used include GCT, GCC, GCA or GCG. Substitution is preferred. Preferably, the isolated and purified nucleic acid molecule encodes the amino acid sequence of SEQ ID NO: 2 in which the sorting signal comprises Glu 174, Leu 177, Val 185 and Glu 186 and one or more of the codons encoding the aforementioned amino acids is mutated. Preferably, each of the codons encoding Glu 174

35   and Glu 186 is mutated, preferably mutated to encode alanine.

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Especially preferred is when the isolated and purified nucleic acid molecule encodes the amino acid sequence of SEQ ID NO: 3. Optionally, the isolated and purified nucleic acid molecule encodes a mutation of Leu 177 and/or Val 185, such as a substitution.

Still also in view of the above, the present invention provides an isolated and

5   purified nucleic acid molecule encoding GH in which the three-dimensional conformation of the RSP sorting signal has been altered such that the GH can be constitutively secreted by the NRSP in a mammalian cell. Preferably, the isolated and purified nucleic acid molecule encodes the amino acid sequence of SEQ ID NO: 2 in which the sorting signal comprises Glu 174, Leu 177, Val 185 and Glu 186 and one or more of the codons encoding amino

10   acids outside of the sorting signal is mutated. Preferably, the codon encoding Cys 189 is mutated, preferably mutated to encode serine.

A vector comprising an above-described isolated and purified nucleic acid molecule is also provided. Vectors and vector construction are known in the art (see, e.g., Maniatis et al., *Molecular Cloning: A Laboratory Manual*, Cold Spring Harbor Laboratory, NY

15   (1982)). Preferred vectors for use in the context of the present invention include adenoviral vectors and adeno-associated viral (AAV) vectors. AAV vectors have been developed for a number of AAV serotypes, including AAV2 (see, e.g., Carter et al., U.S. Patents 4,797,368, issued January 10, 1989, and 5,587,308, issued December 24, 1996), AAV4 (see, e.g., Chiorini et al., International Patent Application WO 98/11244, published March 19, 1998)

20   and AAV5 (see, e.g., Chiorini, et al. WO 99/61601, published December 2, 1999). Other vectors which may be useful include lentivirus-based vectors (see, e.g., D'Costa et al., J. Gen. Virol. 82(Pt 2): 425-434 (February 2001); Arya, International Patent Application WO 00/40741, published July 13, 2000; and Morgan et al., International Patent Application WO 98/13511, published April 2, 1998) and hybrid or chimeric viral vectors or vector systems

25   comprising, for example, an adenoviral backbone with lentiviral components (see, e.g., Zheng et al., Nature Biotechnology 18(2): 176-80 (February 2000); Curiel et al., International Patent Application WO 98/22143, published May 28, 1998; Ramsey et al., International Patent Application WO 98/46778, published October 22, 1998; and Ramsey et al., International Patent Application WO 00/17376, published March 30, 2000), or an

30   adenoviral backbone with AAV components (Fisher et al., Human Gene Therapy 7: 2079-2087 (1996)). While the promoter native to hGH can be used, preferably a nonnative promoter is used. Examples of such nonnative promoters include various constitutive and regulatable promoters. Examples of regulatable promoters include inducible, repressible and tissue-specific promoters. Specific examples include viral promoters, preferable

35   adenoviral promoters and AAV promoters, and a promoter that is specific for expression in

the salivary gland, such as the promoter from the amylase gene. Preferably, the promoter is an adenoviral promoter.

Accordingly, an isolated host cell comprising the above-described vector is also provided. Any suitable host cell can be used. Examples include prokaryotic host cells, such
5   as *E. coli*, in particular K12 strain 294 (American Type Culture Collection (ATCC) No. 31446), B, X1776 (ATCC No. 31537), c600, c600hfl, W3110 (ATCC No. 27,325), JM101, HB101, NM522, NM538 and NM539, *Bacillus subtilis, Salmonella typhimurium, Serratia marcescens*, and Pseudomonas. Eukaryotic host cells include, for example, yeast and cells derived from a mammal, including human cell lines. Specific examples of suitable
10   eukaryotic host cells include VERO, HeLa, 3T3, Chinese hamster ovary (CHO) cells, W138 BHK, COS-7 and MDCK. Alternatively, cells from a human to be treated in accordance with the methods described herein can be used as host cells. Methods of introducing vectors into isolated host cells and the culture and selection of transformed host cells *in vitro* are known in the art and include the use of calcium chloride-mediated transformation,
15   transduction, conjugation, triparental mating, DEAE, dextran-mediated transfection, infection, membrane fusion with liposomes, high velocity bombardment with DNA-coated microprojectiles, direct microinjection into single cells, and electroporation (see, e.g., Sambrook et al., *Molecular Biology: A Laboratory Manual*, Cold Spring Harbor Laboratory, NY (1989); Davis et al., *Basic Methods in Molecular Biology* (1986), and
20   Neumann et al., EMBO J. 1: 841 (1982)).

The form of the introduced vector can vary with the rationale underlying the introduction of the vector into the host cell. For example, the nucleic acid can be closed circular, nicked, or linearized, depending on whether the vector is to be maintained extragenomically (i.e., as an autonomously replicating vector), integrated as a provirus or
25   prophage, transiently transfected, transiently infected as with use of a replication-deficient or conditionally replicating virus or phage, or stably introduced into the host genome through double or single crossover recombination events.

In addition to the above, the present invention provides a method of treating GHD in mammals, in particular a human. In one embodiment, the method comprises administering
30   to the mammal an above-described composition, whereupon the GHD in the mammal is treated. While any species of mammal can be used as the source of the GH, desirably the GH is from the same species as the mammal being treated. Any suitable route of administration can be used in the context of this method, including local and systemic administration, such as parenteral, i.e., subcutaneous, intramuscular, intravenous,
35   intraarterial and intraperitoneal administration. Preferably, the composition is administered to the mammal by subsutaneous injection to the mammal. In another embodiment, the

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method comprises administering to the mammal an above-described nucleic acid or vector that expresses an effective amount of the encoded GH, whereupon the GHD in the mammal is treated. As indicated above, while any species can be used as the source of nucleic acid encoding GH, desirably the GH is from the same species as the mammal being treated.

5   While any suitable route of administration can be used in the context of this method, preferably, the vector is administered to the mammal *in vivo*, such as by infusion via the main excretory ducts of the salivary gland ("salivary gland" includes glandulae salivariae majores (parotid, sublingual and submandibular glands) and glandulae salivariae minores of the tongue, lips, cheeks and palate (labial, buccal, molar, palatine, lingual and anterior

10   lingual glands)) of the mammal (see, e.g., Example 4 and the references cited therein and German et al., U.S. Patent No. 5,885,971, issued March 23, 1999). Alternatively, an above-described nucleic acid or vector encoding GH in accordance with the present invention can be contacted with host cells *ex vivo* and subsequently administered to the mammal to be treated. Preferably, the host cells are autologous cells, such as biopsied secretory gland

15   tissue, e.g., salivary gland tissue (see, e.g., German et al., *supra*).

Generally, the effective amount of modified GH administered parenterally per dose is in the range of about 1 μg/kg body weight/day to about 100 μg/kg body weight/day. Usually, the effective amount of modified GH administered parenterally per dose is in the range of about 0.01 mg/kg body weight/day and 10 mg/kg body weight/ day. Even more

20   usually, the effective amount of modified hGH administered parenterally per dose is in the range of about 0.01 μg/kg/day and 1 μg/kg/day. If given continuously, the modified GH is typically administered at a dose rate of about 1μg/kg body weight/hr to about 50 μg/kg body weight/hr, such as by one to four injections per day or by continuous subcutaneous infusions. Administration can be repeated daily, three times per week, every three days or

25   once a month. Typically, administration is repeated about once a day to every 2-3 days.

Desirably, an above-described vector that expresses an effective amount of modified GH is administered. When an above-described nucleic acid or vector is administered to the salivary gland, from about 1 μg to 200 mg, preferably from about 100 μg to 100 mg, more preferably from about 500 μg to 50 mg, most preferably about 10 mg, of vector are

30   administered. If the vector is a viral vector, preferably a tissue concentration of about 10^2 to about 10^{12} viral particles per ml is attained. Generally, the amount of vector necessary can be extrapolated from animal models. For example, the amount of DNA to be administered to a human is about 10-100 times the amount of DNA to be administered to a rat. Use of an adequate vector, which is preferably a viral vector, obviates the need for frequent repeat

35   administrations. When a vector is administered, the vector is preferably administered once or up to about once per month.

The present inventive method of treatment can be used to treat other conditions or disease states in addition to GHD in which the administration of hGH would be beneficial. For example, the method can be used to treat frailty associated with ageing, osteoporosis, morbid obesity, cardiac failure, major thermal injury, hypoglycemic unawareness in

5   diabetes mellitus (Sonksen et al. (June 20, 1995), *supra*), various acute and chronic catabolic conditions (Murray et al. (July 2000), *supra*; Mehls et al. (April 2000), *supra*) and intoxication with poisonous substances that are degraded in the liver by microsomal enzymes (Jorgensen (March 28, 1989), *supra*).

A method of making a GH in which the RSP sorting signal is mutated is also

10   provided. The method comprises mutating one or more amino acids in the RSP sorting signal in GH, whereupon a GH in which the RSP sorting signal is mutated is obtained. As indicated above, methods of mutating amino acids are known in the art. Accordingly, a GH with a mutated RSP sorting signal obtained in accordance with such a method is also provided.

15   Further provided is a method of making a GH in which the three-dimensional conformation of the RSP sorting signal is altered. The method comprises mutating one or more amino acids outside of the RSP sorting signal so that the three-dimensional conformation of the amino acids of the RSP sorting signal in GH is altered, whereupon a GH with an RSP having an altered three-dimensional conformation is obtained. Methods of

20   mutating amino acids are known in the art as indicated above. Accordingly, a GH with an RSP sorting signal having an altered three-dimensional conformation obtained in accordance with such a method is also provided.

Still further provided is a method of making a nucleic acid molecule encoding a GH that can be constitutively secreted by the NRSP in a mammalian cell. The method

25   comprises mutating one or more codons encoding amino acids in the RSP sorting signal in an isolated and purified nucleic acid molecule encoding GH such that, upon expression in a mammalian cell, the GH can be constitutively secreted by the NRSP in the mammalian cell. As indicated above, methods of introducing mutations at the nucleic acid level are known in the art. Accordingly, a nucleic acid molecule encoding a GH with a mutated RSP sorting

30   signal obtained in accordance with such a method is also provided.

Yet still further provided is a method of making a nucleic acid molecule encoding a GH that can be constitutively secreted by the NRSP in a mammalian cell. The method comprises mutating one or more codons encoding amino acids outside of the RSP sorting signal in an isolated and purified nucleic acid molecule encoding GH such that the three-

35   dimensional conformation of the amino acids of the RSP sorting signal in GH is altered and, upon expression in a mammalian cell, the GH can be constitutively secreted by the NRSP in

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the mammalian cell. Methods of introducing mutations at the nucleic acid level are known in the art as indicated above. Accordingly, a nucleic acid molecule encoding a GH with an RSP sorting signal having an altered three-dimensional conformation obtained in accordance with such a method is also provided.

Whether or not a recombinantly produced GH is secreted by the NRSP in a mammalian cell and has biological activity can be determined in accordance with the methods set forth in the Examples. An alternative method of determining the biological activity of recombinantly produced GH is described in Zaslavsky, U.S. Patent No. 5,734,024, issued March 31, 1998.

10

EXAMPLES

The following examples serve to illustrate further the present invention and are not intended to limit its scope in any way.

15

Example 1

This example demonstrates the existence of an RSP sorting signal in hGH and describes the essential amino acid residues of the RSP sorting signal motif and their mutation leading to constitutive secretion of hGH.

Experimental data have evidenced the existence of RSP sorting signals in pro-opiomelanocortin (POMC; see, e.g., Cool et al., J. Biol. Chem. 270(15): 8723-8729 (April 14, 1995)) and chromogranin B. Thus, hGH was examined for the presence of an RSP sorting signal.

Initially, the amino acid sequences of growth hormones from multiple species were analyzed to identify evolutionarily conserved amino acids. Since the RSP sorting signals of POMC and chromogranin B included acidic residues, acidic residues in the conserved amino acid sequences were identified.

The X-ray crystal structure of hGH (Brookhaven Protein Database accession no. 1HGU) was then analyzed to determine if the conserved amino acids were exposed on the surface of the molecule and, therefore, accessible to the sorting receptor. Since NMR structural data were available for POMC and the molecular distances between the amino acids of the POMC sorting signal were known, several exposed amino acid residues in hGH having similar molecular distances to those of POMC were selected. The selected amino acid residues were in a region of the hGH molecule that was not involved in the binding of hGH to the physiological GH receptor so as to maintain biological activity for physiological signal transduction.

Molecular distances between amino acid residues of the proposed RSP
sorting signal in hGH as compared to the molecular distances between amino
acid residues of the RSP sorting signal in POMC

	POMC	hGH
Acidic residue 1 (Asp10 for POMC; Glu174 for hGH) to hydrophobic residue 1 (Leu11 for POMC; Leu177 for hGH)	3.82	4.57
Acidic residue 2 (Glu14 for POMC; Glu186 for hGH) to hydrophobic residue 2 (Leu18 for POMC; Leu185 for hGH)	9.29	3.79
Acidic residue 1 (Asp10 for POMC; Glu174 for hGH) to acidic residue 2 (Glu14 for POMC; Glu186 for hGH)	11.6	17.59

Molecular distances are in Angstroms measured between the alpha carbons of each indicated amino acid. The data for growth hormone were obtained from its X-ray crystal structure and the data for POMC were obtained from its NMR structure.

The molecular distances between the amino acid residues of hGH as compared to POMC were sufficiently variable so as to require experimental proof of a sorting signal for hGH. The selected amino acid residues were tested empirically for their ability to direct hGH to the RSP by mutating them and assaying for secretion. Mutants were generated as follows. The wild-type hGH was generated by reverse-transcriptase polymerase chain reaction (RT-PCR) from a human pituitary cDNA library (Clontech, Palo Alto, CA) using a kit from Boehringer-Mannheim (Indianapolis, IN). The hGH cDNA was directionally subcloned into a mammalian expression vector, pcDNA3.1 (InVitrogen, Carlsbad, CA). The plasmid was used as the template for mutagenesis.

Mutagenesis was performed using the Quick Change mutagenesis kit (Stratagene, LaJolla, CA). Briefly, oligonucleotide primers bearing the mutant nucleotide were used in a PCR reaction to amplify the pcDNA3.1-hGH plasmid. The parental DNA was then digested with the restriction endonuclease, *Dpn* 1. The remaining amplified DNA was transformed into a special strain of *E. coli* (from Stratagene) and cultured. Colonies were picked and the plasmid DNA isolated from the colonies was sequenced to confirm that they contained the mutations. For double mutants, a second round of mutagenesis with new mutant primers was carried out using the first mutant as the PCR template.

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The two acidic residues that caused mis-sorting to the constitutive pathway were Glu 174 and Glu 186 and, thus, were determined to be an essential part of the sorting signal motif. Mutation of these glutamic acid residues to alanines, thereby removing the negative charges associated with these residues without causing major structural changes in the loop

5   structure of the sorting signal motif resulted in mis-sorting to the constitutive pathway (i.e., NRSP). It was also determined that mutation of Cys 189 in the loop disrupted stability afforded by the disulfide bridge between Cys 189 and Cys 182. Mutations of either or both of the two cysteine residues can affect the three-dimensional conformation of the loop structure of the sorting signal motif by causing unfolding of the C-terminal loop, thereby

10   disrupting the alignment of the acidic residues necessary for sorting via the RSP.

Example 2

        This example describes a method of assaying mutant GH for secretion.

        The RSP in (neuro)-endocrine cells can be stimulated to release the peptide

15   hormones that are stored within the cells. The mechanism for stimulating these cells is widely used. Typically, this is done by depolarizing the plasma membrane by adding 50 mM K^+ to the medium in the presence of calcium. Alternatively, specific chemicals or other proteins (or peptides) can be added to the medium that bind to a receptor on the plasma membrane and cause stimulated secretion via signal transduction. Primarily, a

20   depolarizing procedure based on the procedure described in Gorr et al., Am. J. Physiol. 277: C121-131 (1999), was used.

        Plasmids of pcDNA3.1-GH or pcDNA3.1-mutant-GH were transiently transfected into PC12 or AtT20 cells, which are model (neuro)-endocrine cell lines that contain both a regulated and a constitutive secretory pathway. Forty-eight hours after transfection with

25   lipofectamine 2000 (Gibco BRL, Rockville, MD), the PC12 cells were pre-incubated twice in a basal buffer (129 mM NaCl, 10 mM HEPES, 5 mM $NaHCO_3$, 4.8 mM KCl, 2.8 mM Glucose, 1.2 mM KH_2PO_4, 1.2 mM $MgCl_2$, and 1 mM $CaCl_2$, pH 7.4) for 15 and 30 minutes, respectively. Afterwards, the cells were incubated in 1 ml of fresh basal buffer for 2 hr. This buffer (M1) was then saved for Western blot analysis and replaced with either of

30   the same volume of basal buffer or stimulation buffer (same as basal buffer but with 79 mM NaCl, 50 mM KCl, 2 mM $BaCl_2$ and no $CaCl_2$) and incubated for 10 min. This buffer ($M2^-$ and $M2^+$) was also saved for Western blot analysis. Immediately upon collection of either of the basal or stimulation buffers, they were centrifuged at 1000 x g to remove cell debris prior to being processed for Western blot analysis. The cells were washed twice with PBS

35   and then harvested in 1 ml of lysis buffer (50 mM HEPES, 150 mM NaCl, 10 mM EDTA, 10 mM sodium pyrophosphate, 100 mM NaF, 2 mM sodium orthovanadate, 1% Triton X-

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100, Boehringer Mannheim complete mini protease cocktail, and 1 μM pepstatin A, pH
7.5). A soluble cell extract (L) was obtained from the lysate after three freeze-thaw cycles
and centrifugation at 13,000 rpm for 10 min. The levels of GH in the media and lysates
were detected by Western blot analysis and/or radioimmunoassay (RIA).

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Example 3

This example describes a method of assaying mutant GH for bioactivity.

32D-rGHR-IRS-1 are special cells that have been engineered to express the rabbit
growth hormone receptor (rGHR) and an insulin response substrate (IRS) (Liang et al.,
10   Endocrinology 140: 1972-1983 (1999)). These cells were provided by Dr. Stuart J. Frank,
University of Alabama. These cells require GH to survive through the action of the rabbit
GH receptor. They normally get sufficient GH to survive from fetal bovine serum, which is
added to the regular culture medium.

In order to test the bioactivity of the GH mutants, the 32D-rGHR-IRS-1 cells were
15   starved of serum for 5 hr and then plated into a 24-well plate. Control serum-free medium,
GH standards (purified protein), and expressed GH (wild-type or mutants in conditioned
medium) were separately added to the serum starved cells and the cells were allowed to
grow for 12-16 hr. The number of viable cells remaining in the wells was then quantified
by trypan blue exclusion. Dead cells absorb the blue dye, whereas viable cells actively
20   exclude the dye. In the presence of either GH standard or any GH expressed from the wild-
type or mutant constructs, the number of viable cells remained high. In the presence of
serum-free medium that contained no GH, the number of viable cells was dramatically
reduced. Thus, the mutant GH proteins were biologically active. In addition, the mutants
appeared to be as biologically active as wild-type GH.

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Example 4

This example describes a method of using an adenoviral vector to transfer a gene
encoding mutant GH to a salivary gland of a mammal *in vivo*.

Adenoviral vectors were constructed in accordance with the methods of Becker et
30   al., Methods Cell. Biol. 43 Pt A: 161-189 (1994); Delporte et al., J. Biol. Chem. 271:
22070-22075 (1996); and He et al., Gene Therapy 5: 537-541 (1998). "First generation"
recombinant adenoviruses (serotype 5, E1-deleted) were used. The adenoviral vectors
encoding mutant GH were transferred to salivary glands, such as parotids, submandibular
glands and sublingual glands, by retrograde infusion following cannulation of the main
35   excretory ducts (see, e.g., Mastrangeli et al., Am. J. Physiol. 266: G1146-G1155 (1994);
Baum et al. Ann. N.Y. Acad. Sci. 875: 294-300 (1999); Baccaglini et al., J. Gene. Med. 3:

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82-90 (2001); Wang et al., J. Dental Res. 79: 701-708 (1999); and O'Connell et al., Cancer Gene Ther. 6: 505-513 (1999)).

All references, including publications, patent applications, and patents, cited herein are hereby incorporated by reference to the same extent as if each reference were individually and specifically indicated to be incorporated by reference and were set forth in its entirety herein.

All amino acid numbering herein is based on the mature proteins. The amino acids are numbered consecutively from the N-terminus to the C-terminus of the mature protein starting with "1" in accordance with convention.

The use of the terms "a" and "an" and "the" and similar referents in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., "such as") provided herein, is intended merely to better illuminate the invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

Preferred embodiments of this invention are described herein, including the best mode known to the inventors for carrying out the invention. Of course, variations of those preferred embodiments will become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for the invention to be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

WHAT IS CLAIMED IS:

1. An isolated and purified growth hormone (GH) in which the regulated secretory pathway (RSP) sorting signal has been mutated.

2. The isolated and purified GH of claim 1, which consists essentially of the amino acid sequence of SEQ ID NO: 2 in which the sorting signal comprises glutamic acid at amino acid position 174 (Glu 174), leucine at amino acid position 177 (Leu 177), valine at amino acid position 185 (Val 185) and glutamic acid at position 186 (Glu 186) and in which one or more of the aforementioned amino acids is mutated.

3. The isolated and purified GH of claim 1 or 2, in which each of Glu 174 and Glu 186 is mutated.

4. The isolated and purified GH of claim 3, in which each of Glu 174 and Glu 186 is mutated by substitution with alanine.

5. The isolated and purified GH of claim 4, in which Phe 191 is substituted with LLGILQISSTVAAARV (SEQ ID NO: 3) and, optionally, Leu 177 and/or Val 185 is/are mutated.

6. The isolated and purified GH of claim 5, in which Leu 177 and/or Val 185 is/are mutated by substitution with another amino acid.

7. An isolated and purified GH in which the three-dimensional conformation of the RSP sorting signal has been altered.

8. The isolated and purified GH of claim 7, which consists essentially of the amino acid sequence of SEQ ID NO: 2 in which the sorting signal comprises Glu 174, Leu 177, Val 185 and Glu 186 and in which one or more amino acids outside of the RSP sorting signal is mutated.

9. The isolated and purified GH of claim 7 or 8, in which cysteine at amino acid position 189 (Cys 189) is mutated.

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10.   The isolated and purified GH of claim 9, in which Cys 189 is mutated by substitution with serine.

11.   A composition comprising an effective amount of the isolated and purified GH of claim 1 in an excipient.

12.   A composition comprising an effective amount of the isolated and purified GH of any of claims 2-6 in an excipient.

13.   A composition comprising an effective amount of the isolated and purified GH of any of claims 7-10 in an excipient.

14.   An isolated and purified nucleic acid molecule encoding GH in which the RSP sorting signal has been mutated such that the GH can be constitutively secreted by the nonregulated secretory pathway (NRSP) in a mammalian cell.

15.   The isolated and purified nucleic acid molecule of claim 14, which encodes the amino acid sequence of SEQ ID NO: 2 in which the sorting signal comprises Glu 174, Leu 177, Val 185 and Glu 186 and one or more of the codons encoding the aforementioned amino acids is mutated.

16.   The isolated and purified nucleic acid molecule of claim 14 or 15, in which each of the codons encoding Glu 174 and Glu 186 is mutated.

17.   The isolated and purified nucleic acid molecule of claim 16, in which each of the codons encoding Glu 174 and Glu 186 is mutated to encode alanine.

18.   The isolated and purified nucleic acid molecule of claim 17, in which the codon encoding Phe 191 is substituted with codons encoding LLGILQISSTVAAARV and, optionally, the codon(s) encoding Leu 177 and/or Val 185 is/are mutated.

19.   The isolated and purified nucleic acid molecule of claim 18, in which the codon(s) encoding Leu 177 and/or Val 185 is/are mutated to encode amino acid substitution(s).

20.   An isolated and purified nucleic acid molecule encoding GH in which the three-dimensional conformation of the RSP sorting signal has been altered such that the GH can be constitutively secreted by the NRSP in a mammalian cell.

21.   The isolated and purified nucleic acid molecule of claim 20, which encodes the amino acid sequence of SEQ ID NO: 2 in which the sorting signal comprises Glu 174, Leu 177, Val 185 and Glu 186 and one or more of the codons encoding amino acids outside of the sorting signal is mutated.

22.   The isolated and purified nucleic acid molecule of claim 20 or 21, in which the codon encoding Cys 189 is mutated.

23.   The isolated and purified nucleic acid molecule of claim 22, in which the codon encoding Cys 189 is mutated to encode serine.

24.   A vector comprising the isolated and purified nucleic acid molecule of claim 14.

25.   A vector comprising the isolated and purified nucleic acid molecule of any of claims 15-19.

26.   A vector comprising the isolated and purified nucleic acid molecule of any of claims 20-23.

27.   An isolated host cell comprising the vector of claim 24.

28.   An isolated host cell comprising the vector of claim 25.

29.   An isolated host cell comprising the vector of claim 26.

30.   A method of treating growth hormone deficiency (GHD) in a mammal, which method comprises administering to the mammal the composition of claim 11, whereupon the GHD in the mammal is treated.

31.   The method of claim 30, wherein the composition is administered to the mammal by subcutaneous injection to the mammal.

32.   A method of treating GHD in a mammal, which method comprises administering to the mammal the composition of claim 12, whereupon the GHD in the mammal is treated.

33.   The method of claim 32, wherein the composition is administered to the mammal by subcutaneous injection to the mammal.

34.   A method of treating GHD in a mammal, which method comprises administering to the mammal the composition of claim 13, whereupon the GHD in the mammal is treated.

35.   The method of claim 34, wherein the composition is administered to the mammal by subcutaneous injection to the mammal.

36.   A method of treating GHD in a mammal, which method comprises administering to the mammal the isolated and purified nucleic acid molecule of claim 14 or the vector of claim 24, which expresses an effective amount of the encoded GH, whereupon the GHD in the mammal is treated.

37.   The method of claim 36, wherein the vector is administered to the mammal by infusion via the main excretory ducts of the salivary gland of the mammal.

38.   A method of treating GHD in a mammal, which method comprises administering to the mammal the isolated and purified nucleic acid molecule of any of claims 15-19 or the vector of claim 25, which expresses an effective amount of the encoded GH, whereupon the GHD in the mammal is treated.

39.   The method of claim 38, wherein the vector is administered to the mammal by infusion via the main excretory ducts of the salivary gland of the mammal.

40.   A method of treating GHD in a mammal, which method comprises administering to the mammal the isolated and purified nucleic acid molecule of any of claims 20-23 or the vector of claim 26, which expresses an effective amount of the encoded GH, whereupon the GHD in the mammal is treated.

41.   The method of claim 40, wherein the vector is administered to the mammal by infusion via the main excretory ducts of the salivary gland of the mammal.

42.   A method of treating GHD in a mammal, which method comprises administering to the mammal host cells which have been contacted *ex vivo* with the isolated and purified nucleic acid molecule of claim 14 or the vector of claim 24, which expresses an effective amount of the encoded GH, whereupon the GHD in the mammal is treated.

43.   The method of claim 42, wherein the host cells are autologous to the mammal.

44.   The method of claim 43, wherein the host cells are derived from a biopsy of secretory gland tissue.

45.   The method of claim 44, wherein the secretory gland tissue is salivary gland tissue.

46.   A method of treating GHD in a mammal, which method comprises administering to the mammal host cells which have been contacted *ex vivo* with the isolated and purified nucleic acid molecule of any of claims 15-19 or the vector of claim 25, which expresses an effective amount of the encoded GH, whereupon the GHD in the mammal is treated.

47.   The method of claim 46, wherein the host cells are autologous to the mammal.

48.   The method of claim 47, wherein the host cells are derived from a biopsy of secretory gland tissue.

49.   The method of claim 48, wherein the secretory gland tissue is salivary gland tissue.

50.   A method of treating GHD in a mammal, which method comprises administering to the mammal host cells which have been contacted *ex vivo* with the isolated and purified nucleic acid molecule of any of claims 20-23 or the vector of claim 26, which

expresses an effective amount of the encoded GH, whereupon the GHD in the mammal is treated.

51.   The method of claim 50, wherein the host cells are autologous to the mammal.

52.   The method of claim 51, wherein the host cells are derived from a biopsy of secretory gland tissue.

53.   The method of claim 52, wherein the secretory gland tissue is salivary gland tissue.

54.   A method of making a GH in which the RSP sorting signal is mutated, which method comprises mutating one or more amino acids in the RSP sorting signal in GH, whereupon a GH in which the RSP sorting signal is mutated is obtained.

55.   A GH with a mutated RSP sorting signal obtained in accordance with the method of claim 54.

56.   A method of making a GH in which the three-dimensional conformation of the RSP sorting signal is altered, which method comprises mutating one or more amino acids outside of the RSP sorting signal so that the three-dimensional conformation of the amino acids of the RSP sorting signal in GH is altered, whereupon a GH with an RSP having an altered three-dimensional conformation is obtained.

57.   A GH with an RSP sorting signal having an altered three-dimensional conformation obtained in accordance with the method of claim 56.

58.   A method of making a nucleic acid molecule encoding a GH that can be constitutively secreted by the NRSP in a mammalian cell, which method comprises mutating one or more codons encoding amino acids in the RSP sorting signal in an isolated and purified nucleic acid molecule encoding GH such that, upon expression in a mammalian cell, the GH can be constitutively secreted by the NRSP in the mammalian cell.

59.   A nucleic acid molecule encoding a GH with a mutated RSP sorting signal obtained in accordance with the method of claim 58.

60.   A method of making a nucleic acid molecule encoding a GH that can be constitutively secreted by the NRSP in a mammalian cell, which method comprises mutating one or more codons encoding amino acids outside of the RSP sorting signal in an isolated and purified nucleic acid molecule encoding GH such that the three-dimensional conformation of the amino acids of the RSP sorting signal in GH is altered and, upon expression in a mammalian cell, the GH can be constitutively secreted by the NRSP in the mammalian cell.

61.   A nucleic acid molecule encoding a GH with an RSP sorting signal having an altered three-dimensional conformation obtained in accordance with the method of claim 60.

FIG. 1

SEQ ID NO: 1

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  1 atggctacag gctcccggac gtccctgctc ctggcttttg gcctgctctg cctgccctgg
 61 cttcaagagg gcagtgcctt cccaaccatt cccttatcca ggcttttttga caacgctatg
121 ctccgcgccc atcgtctgca ccagctggcc tttgacacct accaggagtt tgaagaagcc
181 tatatcccaa aggaacagaa gtattcattc ctgcagaacc cccagacctc cctctgtttc
241 tcagagtcta ttccgacacc ctccaacagg gaggaaacac aacagaaatc caacctagag
301 ctgctccgca tctccctgct gctcatccag tcgtggctgg agcccgtgca gtccctcagg
361 agtgtcttcg ccaacagcct ggtgtacggc gcctctgaca gcaacgtcta tgacctccta
421 aaggacctag aggaaggcat ccaaacgctg atggggaggc tggaagatgg cagcccccgg
481 actgggcaga tcttcaagca gacctacagc aagttcgaca caaactcaca caacgatgac
541 gcactactca gaaactacgg gctgctctac tgcttcagga aggacatgga caaggtcgag
601 acattcctgc gcatcgtgca gtgccgctct gtggagggca gctgtggctt c
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SEQ ID NO: 2

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  1 matgsrtsll lafgllclpw lqegsafpti plsrlfdnam lrahrlhqla fdtyqefeea
 61 yipkeqkysf lqnpqtslcf sesiptpsnr eetqqksnle llrisllliq swlepvqslr
121 svfanslvyg asdsnvydll kdleegiqtl mgrledgspr tgqifkqtys kfdtnshndd
181 allknyglly cfrkdmdkve tflrivqcrs vegscgf
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SEQ ID NO: 3

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  1 matgsrtsll lafgllclpw lqegsafpti plsrlfdnam lrahrlhqla fdtyqefeea
 61 yipkeqkysf lqnpqtslcf sesiptpsnr eetqqksnle llrisllliq swlepvqslr
121 svfanslvyg asdsnvydll kdleegiqtl mgrledgspr tgqifkqtys kfdtnshndd
181 allknyglly cfrkdmdkve tflrivqcrs vegscgllgi lqisstvaaa rv
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Amino acid designations in the specification reference the mature hGH protein, whereas SEQ ID NO: 2 (and SEQ ID NO: 1, which encodes SEQ ID NO: 2) is the amino acid sequence of the precursor hGH protein.

Cys 189 in mature hGH is Cys 215 in precursor hGH of SEQ ID NO: 2.
Glu 186 in mature hGH is Glu 212 in precursor hGH of SEQ ID NO: 2.
Val 185 in mature hGH is Val 211 in precursor hGH of SEQ ID NO: 2.
Glu 174 in mature hGH is Glu 200 in precursor hGH of SEQ ID NO: 2.
Leu 177 in mature hGH is Leu 203 in precursor hGH of SEQ ID NO: 2.
Phe 191 in mature hGH is Phe 217 in precursor hGH of SEQ ID NO: 2.